Senior Thesis

Geochemistry of an Acid-contaminated Stream in New Lexington, Ohio

by
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Approved by:

Gunter Faure

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Abstract

Rivers draining abandoned and reclaimed coal mining areas are characterized by high concentrations of trace metals and low pH values, and therefore are said to be contaminated by "acid-mine drainage" or AMD. The streams and tributaries in New Lexington of Perry County, Ohio, possess these characteristics due to mining of coal in the area. The pH of the water in Lexington Creek and Rush Creek reaches a low of 2.6. In addition, the water contains the following trace metals listed in order of their highest concentrations: magnesium = 174.0 ppm, calcium = 162.0 ppm, manganese = 44.81 ppm, sodium = 41.2 ppm, iron = 35.03 ppm, potassium = 5.18 ppm, zinc = 1.61 ppm, nickel = 0.776 ppm, cobalt = 0.749 ppm, strontium = 0.647 ppm, yttrium = 0.392 ppm, lead = 0.206 ppm, barium = 0.178 ppm, lanthanum = 0.154 ppm, arsenic = 0.073 ppm, copper = 0.068 ppm, chromium = 0.014 ppm, and molybdenum = 0.01 ppm. The water in Lexington Creek and Rush Creek also has high concentrations of suspended sediment, primarily ferric hydroxide, up to 180 ppm. The suspended sediment is a potential health problem because the ferric hydroxide sorbs anions at low pH and releases them at neutral pH. This metal-rich sediment accumulates on the stream beds within the city of New Lexington.

A three-component mixing diagram was used to determine how mixing among the tributaries produced water with a specific chemical composition in Rush Creek. This water contained 108 ppm Ca, 58.4 ppm Mg, 20.6 ppm Na, 4.02 ppm K, and 1.46 ppm Fe.

In addition, the water of Lexington Creek was treated as a mixture of three components: ground water, meteoric water, and mine effluent. The abundances of each component were determined to be: ground water = 65%, meteoric water = 9.6%, and

acid-mine drainage reaching a high of 25% at the confluence of Lexington and Rush Creeks.

The ferric hydroxide recovered from the sediment of sample 7 consists of many trace elements, some of which are: As = 67,700 ppm; V = 28,000 ppm; Zn = 6260 ppm; Cr = 5750 ppm; Cu = 2320 ppm; and Ba = 1350 ppm. Many of the trace elements found in the ferric hydroxide are toxic and could be released into the water if the pH increases. Therefore, 28 years after mining has stopped, metal rich sediment is being deposited on the streambed channels, and the water of Lexington Creek is significantly contaminated by acid-mine drainage

Introduction

Contaminated surface waters discharged by abandoned coal mines present a health threat not only in central Ohio, but throughout the world even after these mines were reclaimed after the coal had been removed. The study site of New Lexington, Ohio, was chosen because of its accessibility and location (Figure 1). Reclamation and reforestation of old mining areas creates the illusion of a totally recuperated landscape. Many believe that after reclamation the abandoned mines no longer pose a potential health threat, but in this study it is evident that even after 28 years (Ohio Division of Mines Report, Annual Reports, 1972-1979), acid-mine drainage is still a problem in central Ohio, as it is in many other communities around the world.

The occurrence of trace elements in coal was discussed in detail in a book entitled: Environmental Aspects of Trace Elements in Coal, which was a compilation by

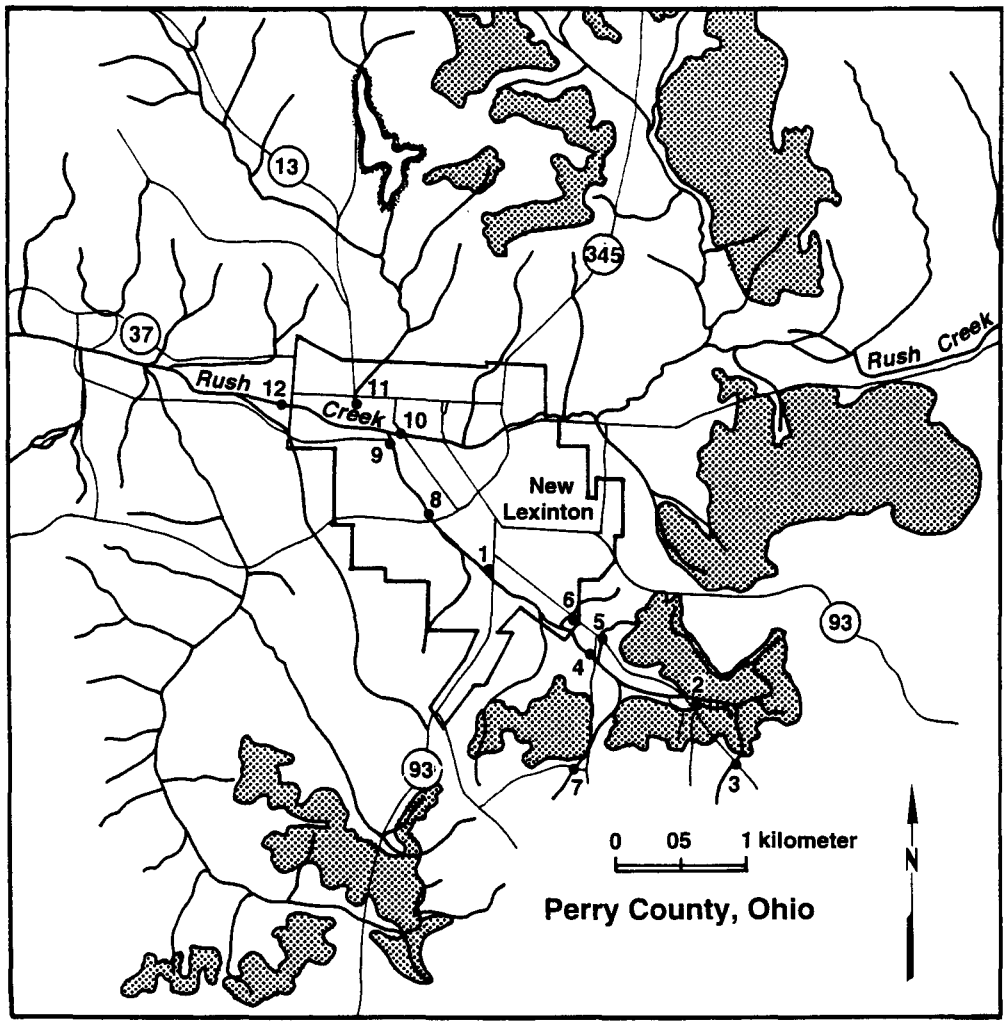


Figure 1. Map of the drainage basin of Lexington Creek and Rush Creek in New Lexington, Ohio. New Lexington is located in Perry County along State Route 13. The collecting sites are numbered 1 through 12 in the order the samples were taken. The speckled areas are abandoned and/or reclaimed surface coal mines. The enclosed area with a dotted perimeter is a lake.

several authors. For example, Gough and Severson (1995) addressed the problems arising from mine reclamation and the impact that trace elements have on the ecosystem. The Surface Mining Control and Reclamation Act (SMCRA), which specified the criteria for mine reclamation, does not address the problem of trace-element concentrations in overburden materials (Gough and Severson, 1995). It does, however, state the suggested trace element limits for livestock drinking water and for aquatic organisms. The trace element limits, suggested by the SMCRA, are compared to the data obtained from the water samples of Lexington and Rush Creeks in Appendix A of this report.

Water from acid-mine drainage has a low pH due to the oxidation of pyrite (FeS_2) and other sulfide minerals.

$$2FeS_2 + 7O_2 + 2H_2O \leftrightarrow 2Fe^{2+} + 4H^+ + 4SO_4^{2-}$$

$$4Fe^{2+} + O_2 + 4H^+ \leftrightarrow 4Fe^{3+} + 2H_2O$$

$$Fe^{3+} + 3H_2O \leftrightarrow Fe(OH)_3 + 3H^+ \text{ (Faure, 1998)}$$

As pyrite is oxidized, hydrogen ions, sulfate ions, and ferrous ions are released. The free hydrogen ions produce acidic water. Ferrous ions react with oxygen and yield ferric ions, which are then hydrolyzed to produce ferric hydroxide. Pyrite occurs naturally in coal; therefore, water discharged by open-pit coal mines is enriched in iron, sulfate, and ferric hydroxide. Ferric hydroxide is a yellow-orange precipitate that accumulates on the rocks and sediment in the stream and is a good indicator that the water is acid-contaminated.

The ferric hydroxide sorbs anions at low pH and cations at higher pH. Sorption of the ions is dependent on their ionic radii. As the pH increases, the toxic cations are removed from the water due to sorption, but equally toxic anions are released into the water. In this way, contaminated stream water naturally cleans itself as groundwater

enters and the pH shifts to higher values, becoming more neutral as the water continues downstream. With higher pH, the ferric ions are no longer in solution but form ferric hydroxide. Therefore, the shift from highly acidic water to more neutral water results in the formation of metal-rich sediment, which is suspended in the water or settles out and accumulates on the stream bed. The EPA regulates water quality in streams, but not the sediment on the stream beds. Since this sediment can be re-acidified, the sorbed cations can go back into solution, thereby posing a health threat to humans who drink this water.

Field Area

The site of this study is Perry County, Ohio, which is ranked fourth after Belmont, Harrison, and Jefferson counties as a coal producer in Ohio (Ohio Dept. of Natural Resources). Lexington Creek (Figure 1) is a tributary to Rush Creek, which flows west and eventually discharges into the Scioto River. Since the tributary does not have a name, it has been unofficially named Lexington Creek for the purpose of the study. Lexington Creek has numerous small tributaries, many of which originate from old mine spoils, which are about 28 years old (Ohio Division of Mines Report, Annual Reports, 1969-1972). Large-scale surface mining at the Sunny Hill Mines operated by the Peabody Coal Company (Ohio Division of Mines Reports, 1969-1972) ceased in 1972. The study area is no longer being mined and has been reclaimed by reforestation. Nevertheless, acid mine drainage is still contaminating Lexington Creek and some of its tributaries.

Geology

The geology of the study area is part of the Alleghany Series of the Pennsyvanian System, the dominant lithologies of which are coal, clay, limestone, shale, and sandstone. In stratigraphic order, the Allegheny Series consists of the Brookville, Putnam Hill, Clarion, Lower Kittanning, Hamden limestone, Oakhill clay, Strasburg coal, Middle Kittanning, Lower Freeport, and Upper Freeport Members. The coal seam mined near New Lexington is the Middle Kittanning coal Member, which is 66 inches thick. The Middle Kittanning coal Member is part of the Middle Kittanning cyclothem, which lies stratigraphically above the Strasburg cyclothem, and stratigraphically below the Lower Freeport cyclothem.

Methodology

Collection

Water samples were collected on April 11, 1999 from Lexington Creek in New Lexington (Figure 1). The samples were stored in new 250 mL and 500 mL polyethylene bottles. The bottles were rinsed with creek water at each site, and then filled to the top to eliminate headspace. The pH of the water was measured at each location.

Analysis of Water

The samples were filtered under vacuum through preweighed 0.45 micrometer acetate filters to recover sediment suspended in the water. The filtered water was acidified to about pH=2 by adding two drops of concentrated reagent-grade nitric acid. The filtered and acidified water samples were analyzed by inductively coupled plasma

optical emission spectrometry (ICP-OES) by XRAL Laboratories in Toronto, Canada. The analytical results and detection limits are listed in Appendix B.

Recovery and Analysis of Sediment

The filters containing the sediment were air-dried and reweighed to determine the mass of sediment that was suspended in the water. Subsequently, the acetate filters of samples 7 and 10 were dissolved in reagent-grade acetone to recover the sediment. These sediment samples were composed of a combination of clays, silts, ferric hydroxide, and organic material. Only the sediment of sample 7 was prepared for analysis because its high ferric hydroxide content indicated that it contained mine effluent. Sample 10 was not analyzed due to the absence of ferric hydroxide. 50 mL of 2 N HCl was added to dissolve the dried sediment recovered at site 7. This solution was centrifuged to separate the dissolved ferric hydroxide from the insoluble siliciclastic sediment. The hydrochloric acid solution of the sediment was diluted to 100 mL in a volumetric flask for analysis by ICP-OES. The remaining insoluble sediment was air-dried and weighed. The weight of the acid-insoluble sediment was subtracted from the total weight of the sediment in order to determine the weight of the acid-soluble ferric-hydroxide fraction.

Presentation of Data

Suspended Sediment

The sediment concentrations recovered from each water sample are listed in Appendix C. The sediment load of Lexington Creek in Figure 2B increased downstream

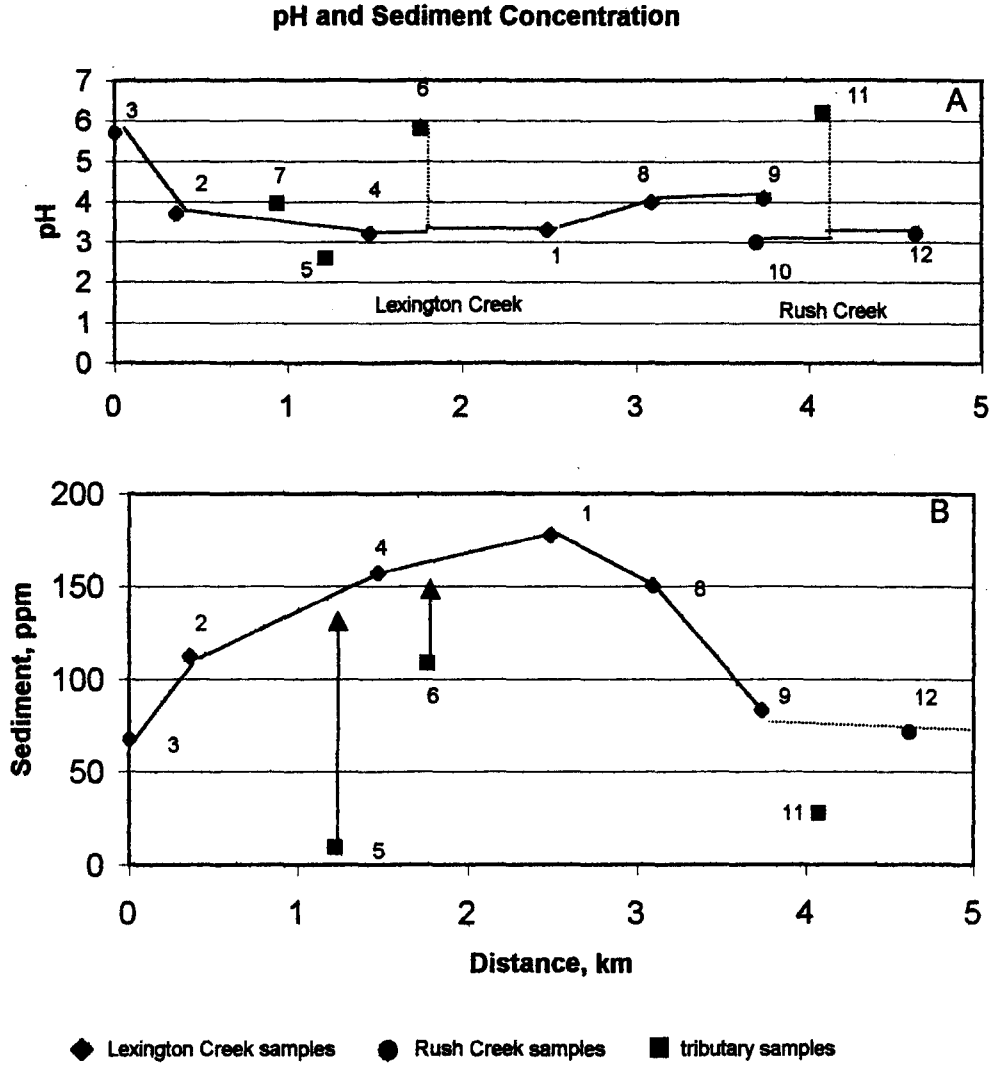


Figure 2. A. pH vs. distance downstream of Lexington Creek and Rush Creek. pH=5.8 at the head of the creek and drops to a low of 2.6 after flowing through old mining areas. B. Sediment load versus distance downstream. Samples 7 and 10 are not included due to intentional collecting of excess sediment.

from 67.6 ppm at site 3 to 177.6 ppm at site 1 and then decreased to 83.2 ppm at site 9. Tributaries 5, 6, and 11 do not affect the suspended sediment load of Lexington Creek concentrations because they have low discharge. These tributaries also have shallow gradients, resulting in low water velocities and low suspended sediment concentrations. Samples 7 and 10 were excluded from Figure 2B because excess sediment was collected from the bottom of the stream channel and was added to the water samples intentionally. The acid-soluble ferric hydroxide fraction of sample 7 was calculated to be 0.00105 grams.

pH of the Water

The pH of the water of Lexington Creek decreases from 5.8 at site 3 to 3.8 at site 2, a distance of only 360 meters (Figure 2A). There is little change in the pH further downstream, which varies from 3.2 to 4.2. Rush Creek is treated separately and has pH ~ 3.0 to 3.2. Samples from tributaries 6 and 11 have neutral pH because no mining has occurred near the sources of these tributaries. Tributary 7, which is a source of acid-mine drainage, has a pH of 3.95.

Alkali Metals

The sodium and potassium concentrations of the water in Lexington Creek increase downstream from 3.7 ppm to 28.7 ppm and 1.33 ppm to 3.78 ppm, respectively (Figure 3). Tributaries 7, 5, 6, and 11 do not alter the chemical composition of Lexington Creek because they have low discharge.

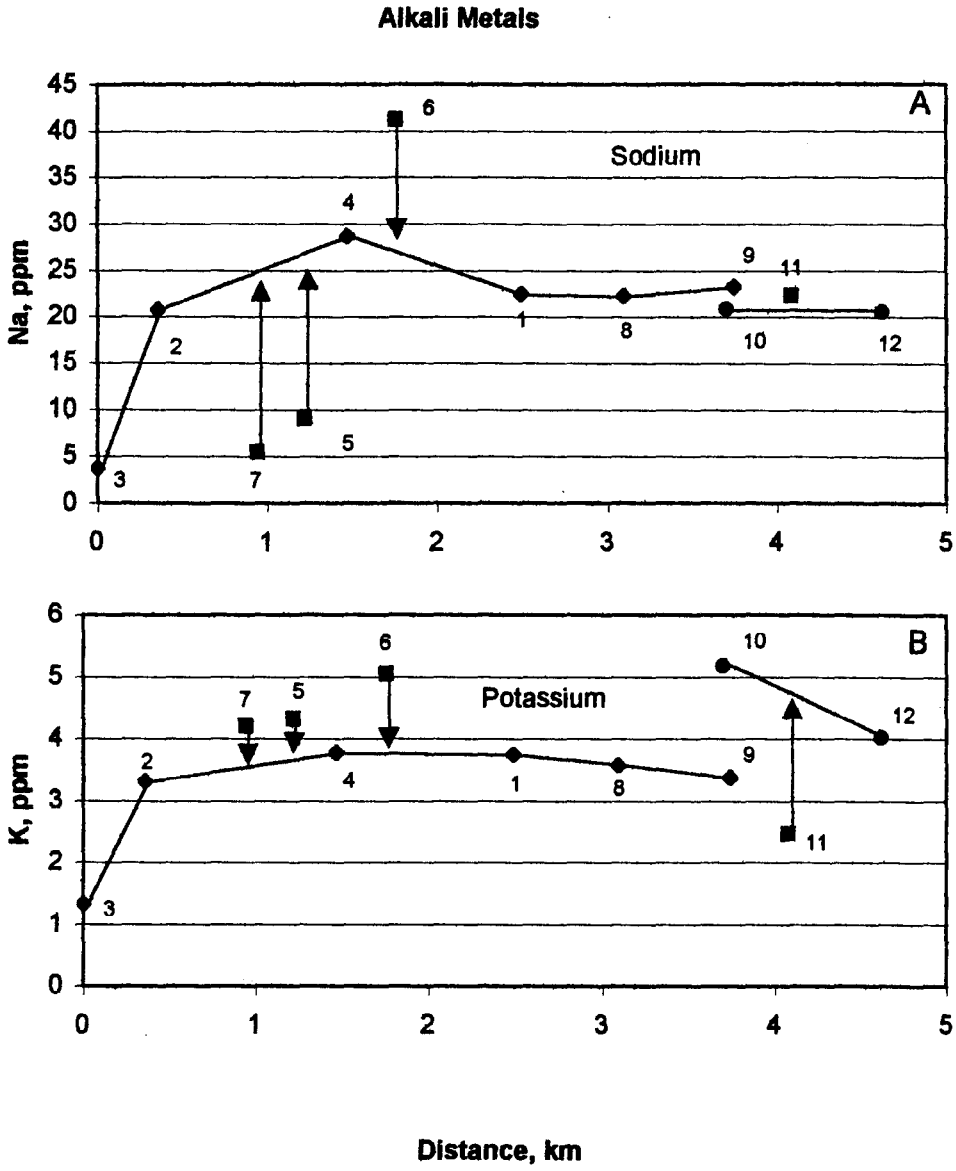


Figure 3. The concentrations of both Na and K sharply increase as pH decreases, but remain constant farther downstream.

Alkaline Earths

The concentrations of the alkaline earths (magnesium, calcium, and strontium) initially increase downstream to site 2 and then remain relatively stable. Figure 4 shows that tributary 7 has high magnesium and calcium concentrations. The water of this stream is also enriched in many trace elements, which will be discussed later. Tributary 7 drains an abandoned mine (Figure 1) and is a source of acid-mine drainage. The strontium concentration of Lexington Creek continues to increase downstream to 0.546 ppm at site 4, where it begins to drop to 0.36 ppm (Figure 5A). Barium has an anomalously high concentration at site 3 (0.18 ppm) and then decreases sharply downstream to 0.03 ppm. The concentration of Ba fluctuates between 0.02 to 0.06 downstream (Figure 5B).

Trace Elements (Lexington Creek)

The trace elements detected by ICP-OES in Figures 6 and 7 are cobalt, nickel, copper, zinc, aluminum, iron, and yttrium. All begin with relatively low concentrations at site 3, rise slightly, and then stabilize. The water of tributary 7 is enriched in several trace metals: cobalt = 0.75 ppm, nickel = 0.78 ppm, zinc = 1.61 ppm, aluminum = 40.85 ppm, iron = 35.03 ppm, and yttrium = 0.39 ppm. Although not shown in Figures 6 and 7, tributary 7 also contains detectable silver at 0.007 ppm and titanium at 0.019 ppm.

Trace Elements (Rush Creek)

Rush Creek also has high trace metal concentrations, including zirconium = 0.037 ppm, silver = 0.009 ppm, molybdenum = 0.01 ppm, arsenic = 0.073 ppm, lead = 0.206 ppm, chromium = 0.014 ppm, scandium = 0.004, and tungsten = 0.073 ppm.

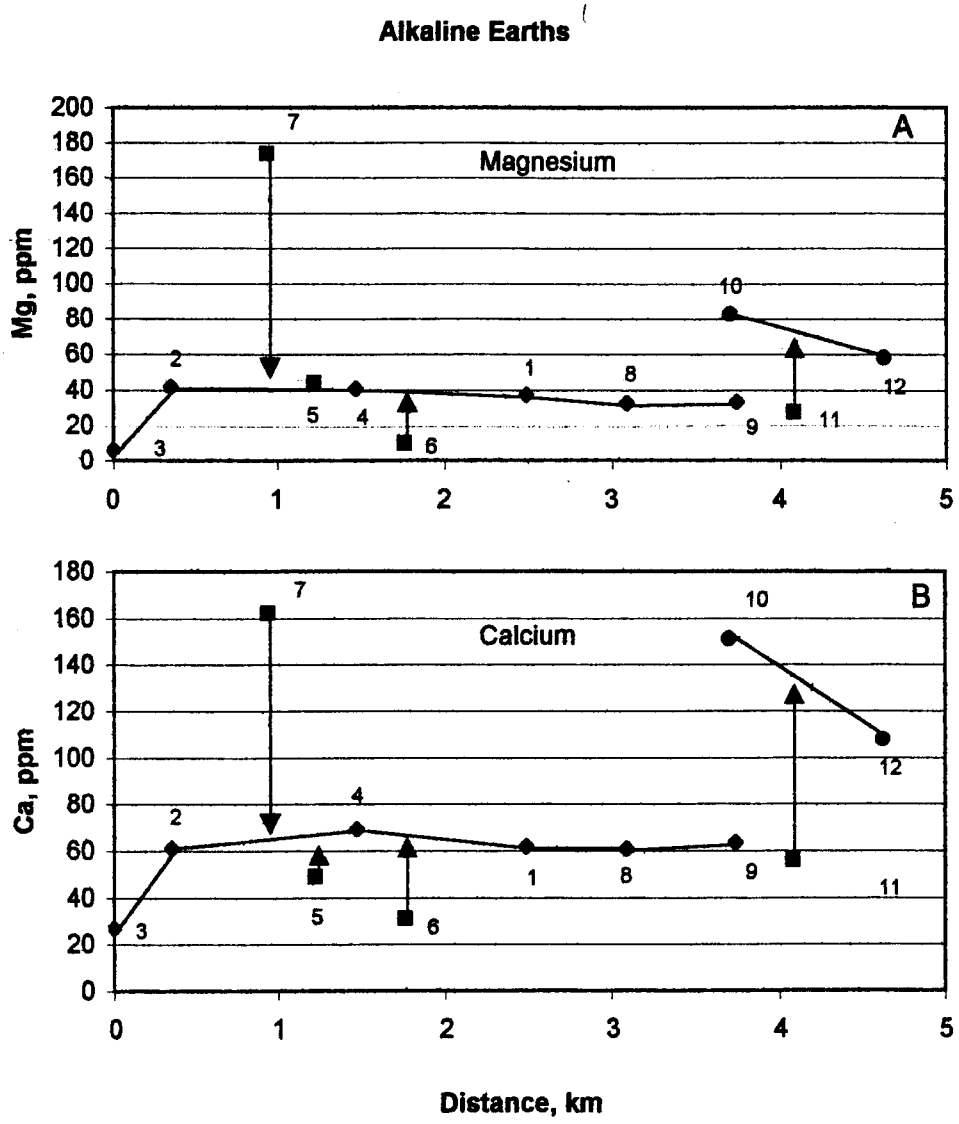


Figure 4. A and B indicate fairly constant concentrations of Mg and Ca. Sample 7 is anomalously high in both elements, but does not affect the average concentration of Lexington Creek.

Alkaline Earths continued

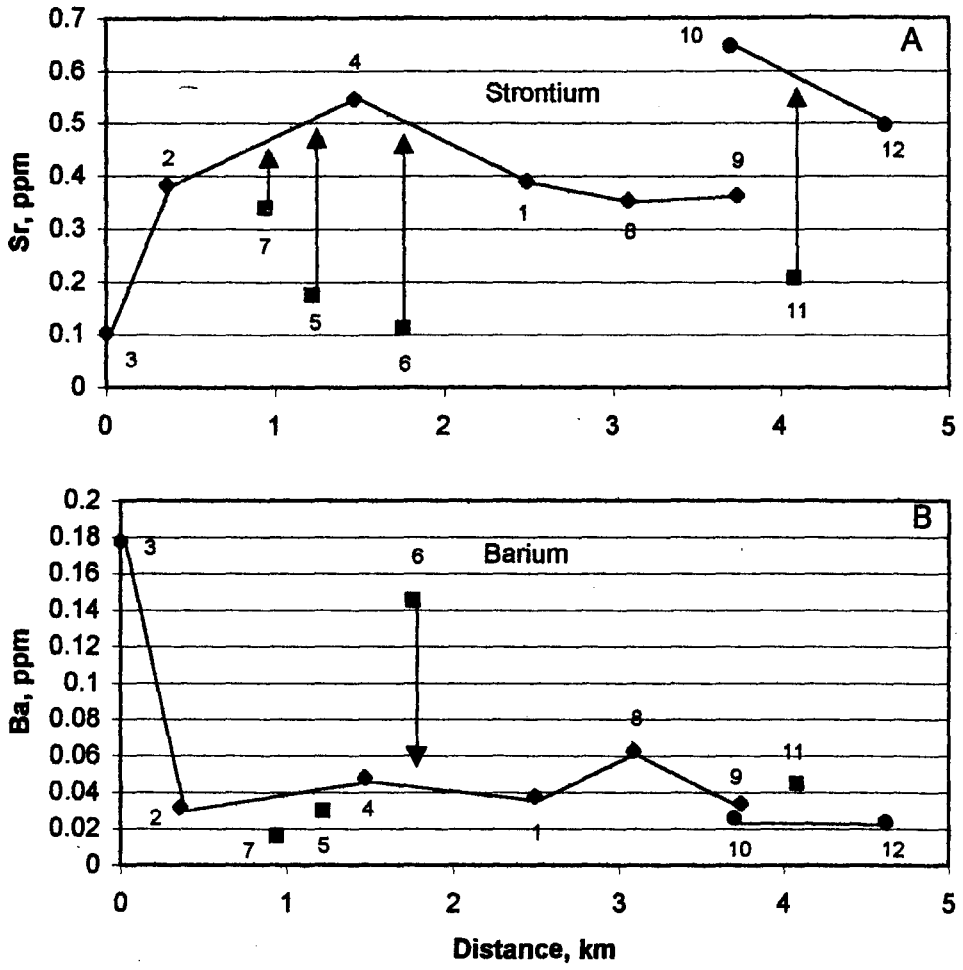


Figure 5. A indicates an increase in Sr, although tributaries 5, 6, and 7 show low concentrations. These do not affect Lexington Creek. B. The barium concentration in sample 3 is anomalously high, decreases sharply, and then remains relatively constant.

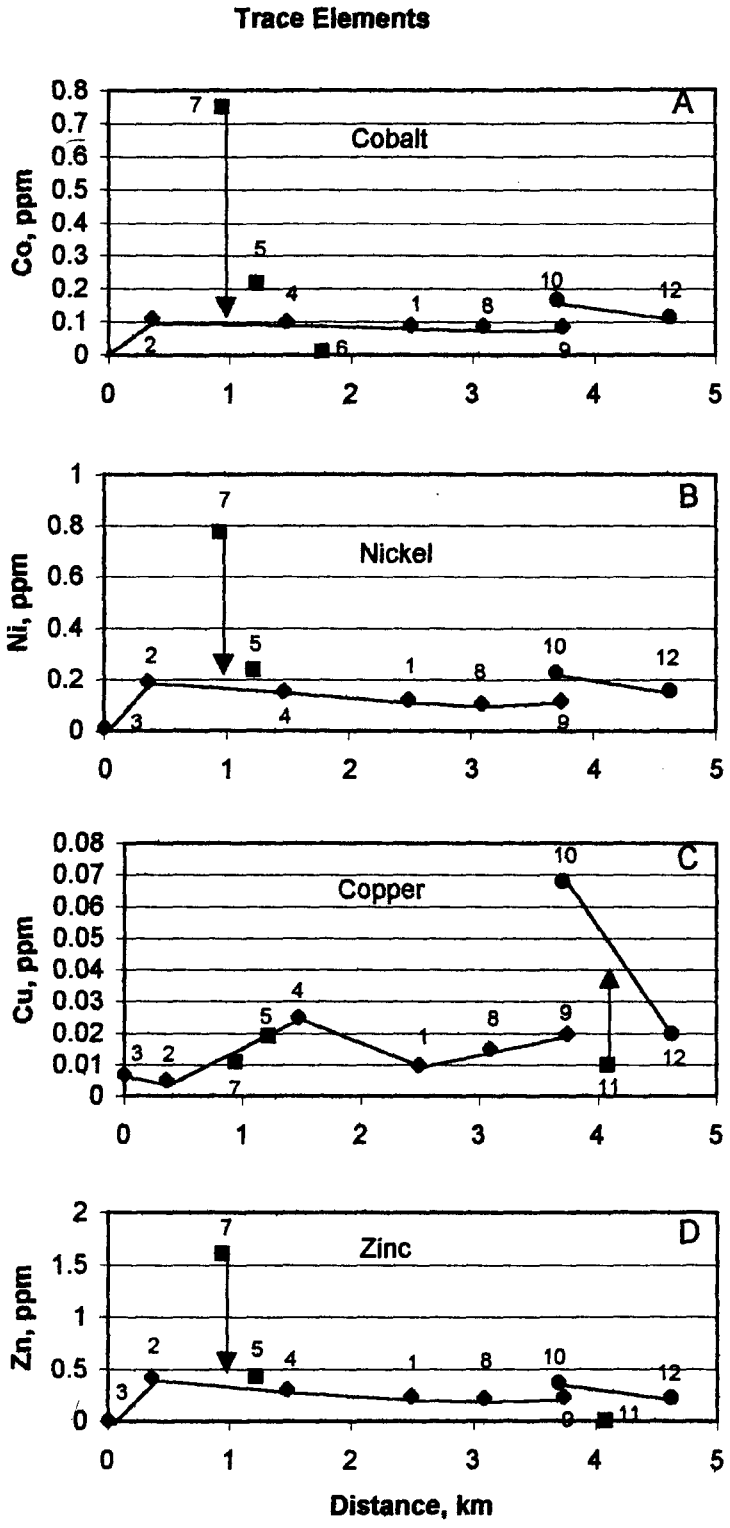


Figure 6. Trace elements cobalt, nickel, copper, and zinc. See Results for explanation.

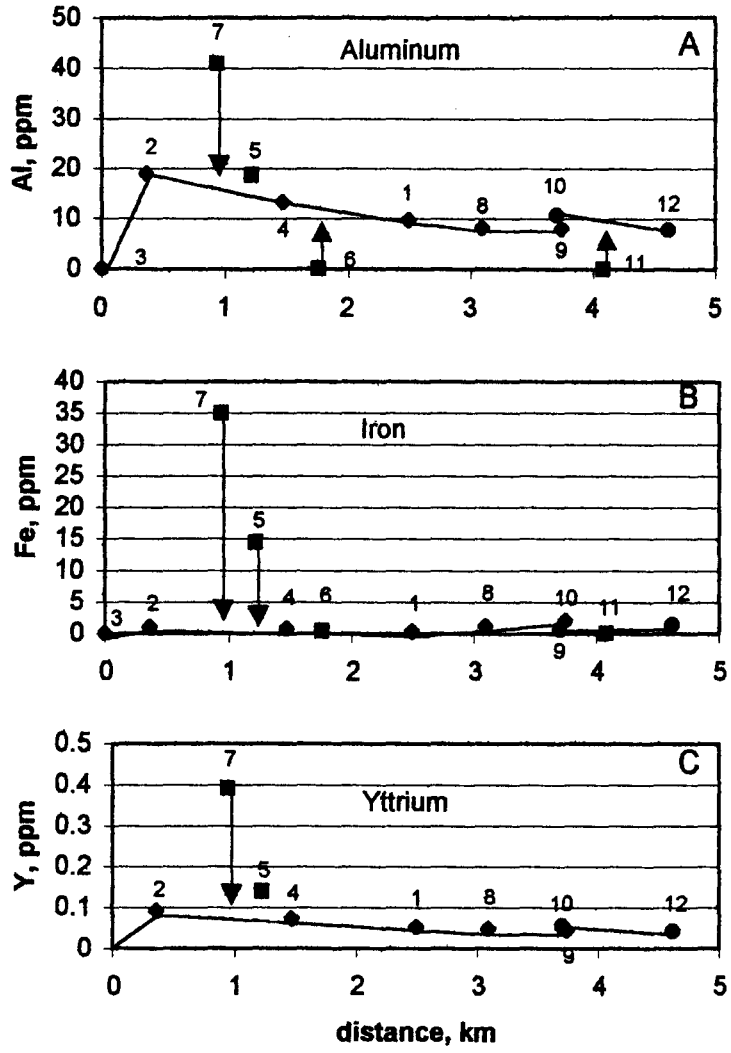


Figure 7. Trace elements cobalt, nickel, copper, zinc, aluminum, iron, and yttrium. See Results for explanation.

Elements that may be present in both streams, but are below the detection limit include: vanadium, cadmium, tin, antimony, and bismuth. Elements that are detectable in both Lexington and Rush Creeks, but are not shown in Figures 3 through 7 are: phosphorous, manganese, and lanthanum.

Interpretation

The chemical composition of the water in Lexington Creek is interpreted in four ways. 1. Variation of sediment load in Lexington Creek. 2. Mixing of water among tributaries. 3. Mixing of water in Lexington Creek. 4. Chemical composition of the ferric hydroxide.

1. Variation of Sediment Load in Lexington Creek

The sediment load of Lexington Creek varies from 67.6 ppm at site 3 to 177.6 ppm at site 1, and then decreases to 83.2 ppm at site 9 (Figure 2B). Possible reasons for the decrease from site 1 to site 9 are: 1. Changes in pH of the water; 2. Dilution; and 3. Decrease of the water velocity. A decrease in pH would cause ferric hydroxide to become more soluble, but from Figure 2A it is evident that the pH actually increased between sites 1 and 9. Dilution is not a likely cause for the decrease in sediment concentration downstream because only one small tributary enters Lexington Creek between sites 1 and 9, which is not enough to dilute the sediment concentration (Figure 1). However, the velocity of Lexington Creek decreases because there is a gradual decrease of the stream gradient allowing sediment to be deposited. Therefore, the decrease of the sediment load is probably caused by a decrease in the stream velocity. This metal-rich sediment is therefore accumulating in the channel of the creek in downtown New Lexington.

2. Mixing of Water among Tributaries

The mixing diagrams in Figure 8 contain the water of Lexington Creek (sample 9), Rush Creek (sample 10), and tributary 11. These locations were chosen because there are three different water sources, which combine to form a final water composition. The composition of the water at site 12 is a mixture of the three components: 9, 10, and 11 downstream from their confluence. The three components mix to form sample 12, in coordinates of Mg-Na, Ca-Na, K-Na, and Fe-Na concentrations expressed in parts per million. If sample 12 were to be an equal mixture of the components, it would lie within the mixing triangle, but it has moved outside of the triangle for each element. Graphs A, B, and C indicate that sample 12 is moving towards a concentration of zero ppm Mg, Ca, K, and Na due to the dilution of sample 12 by meteoric water. Graph D, on the other hand, indicates that concentrations of sample 12 are increasing in Fe and decreasing in Na. The reason for this is because as the water in Rush Creek becomes more dilute, ferric hydroxide is more soluble causing ferric ions to increase in concentration.

3. Mixing of Water in Lexington Creek

The water in Lexington Creek is a mixture of the three components: acid-mine drainage (AMD), groundwater (GW), and meteoric water (MW) as expressed in Figure 9. Sample 7 was chosen to represent AMD due to its high metal concentrations and acidity. Groundwater is represented by sample 6 because it has a relatively neutral pH of 5.8 and low metal concentrations. Meteoric water has low concentrations of all elements and plots near the origin in Figure 9. The concentrations of Mg-Na and Ca-Na are used

Mixing Diagrams

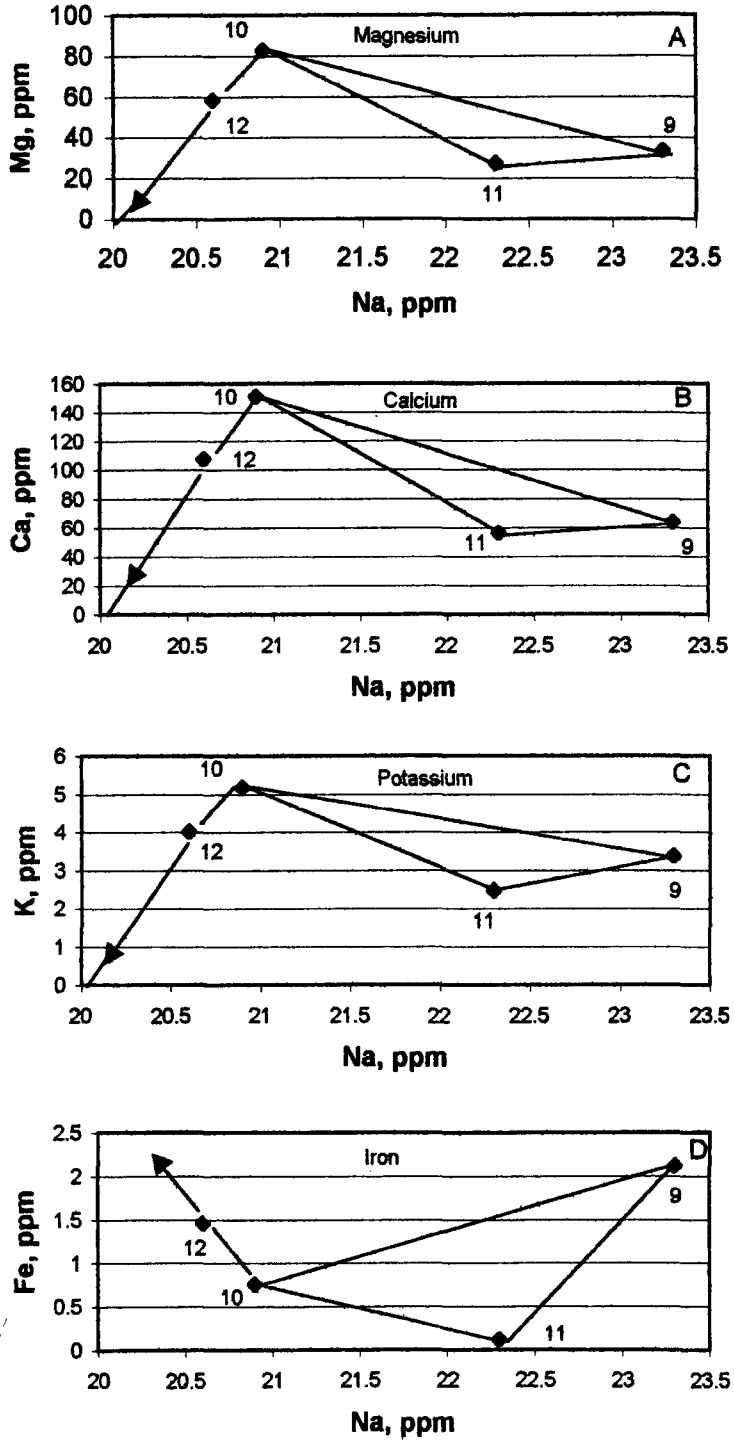


Figure 8. A, B, C show that samples 10 and 12 are similar in element concentrations. 12 has become dilute due to meteoric water, and has moved out of the mixing triangle toward a concentration of zero. D. As the water in Rush Creek becomes more dilute, it becomes less saturated in Fe(OH)3,and it dissolves in solution, and therefore trends toward a higher concentration of Fe.

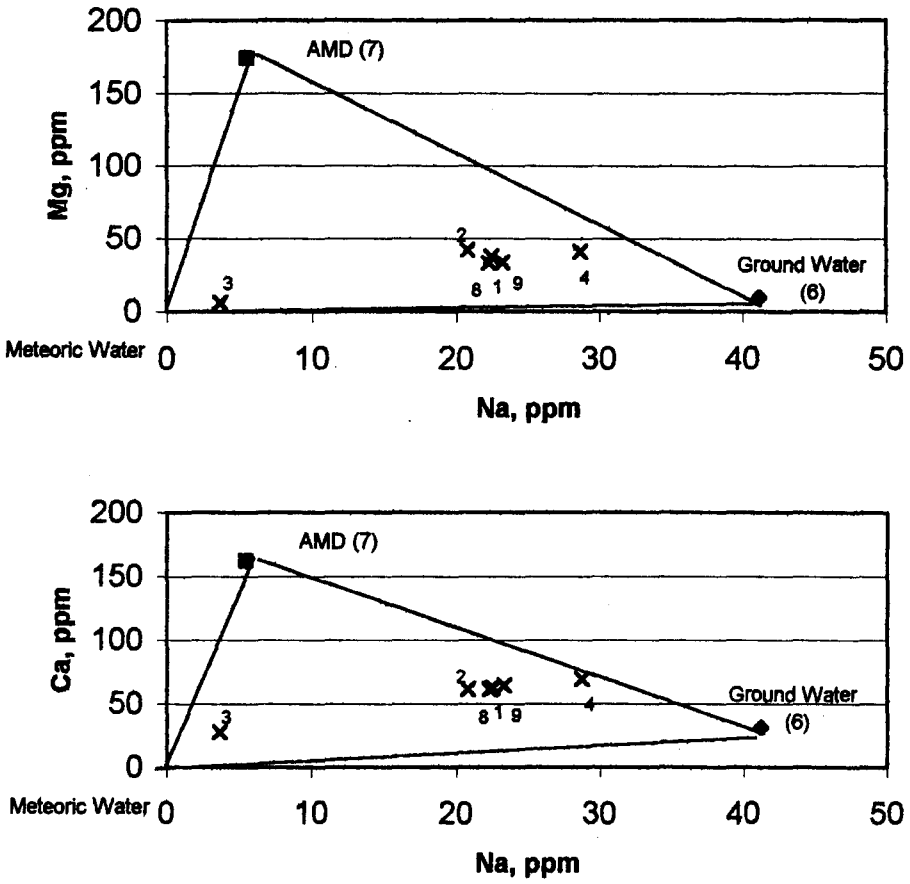


Figure 9. The components of AMD, GW, and MW for each sample site along Lexington Creek. Sample 7 is AMD water. It has elevated concentrations of Mg, Ca, Al, Zn, Co, Ni, Y and pH ~ 4. Sample 6 is Ground Water. It has elevated concentrations of Na and K, and pH ~ 5.8. Meteoric water is represented at the origin, and has concentrations at zero ppm.

because they are conservative elements unaffected by chemical reactions. All of the water samples plot inside 3-component mixing triangles (Figure 9). The mixing triangles were used to resolve the water samples into the three components (Appendix D) by the method of Petz and Faure (1997). The results were plotted (Figure 10) to show how these components vary downstream. AMD increases sharply from 9% at site 3 to 25% at site 2, and continues to remain between 20 and 25% acid mine drainage. Ground water also increases sharply along this stretch of Lexington Creek from 7% to 49%. The abundance of ground water continues to increase downstream from 7% to 65% as more ground water enters the creek. The abundance of meteoric water decreases from 83% at site 3 to 9.6% at site 9 as ground water and AMD continue to increase.

4. Chemical Composition of the Ferric Hydroxide

The sediment retained from site 7 consists primarily of ferric hydroxide. Sample 7 was analyzed by inductively coupled plasma mass spectrometry (ICP-MS). The concentrations of the trace elements in the ferric hydroxide and their detection limits are listed in Appendix E.

Chalcophile Elements

The concentrations of the chalcophile elements in the sediment are: As = 67,700 ppm; Zn = 6260 ppm; Cu = 2320 ppm; Ni = 800 ppm; Pb = 301 ppm; Se = 143 ppm; Ga = 80 ppm; Sn = 57.1 ppm; Te = 38.1 ppm; Cd = 14.3 ppm; Sb = 9.52 ppm; Tl = 1.90 ppm; and In = 0.952 ppm. These concentrations are surprisingly high, especially because the water drains a former coal mine rather than a metallic ore deposit containing sulfide minerals.

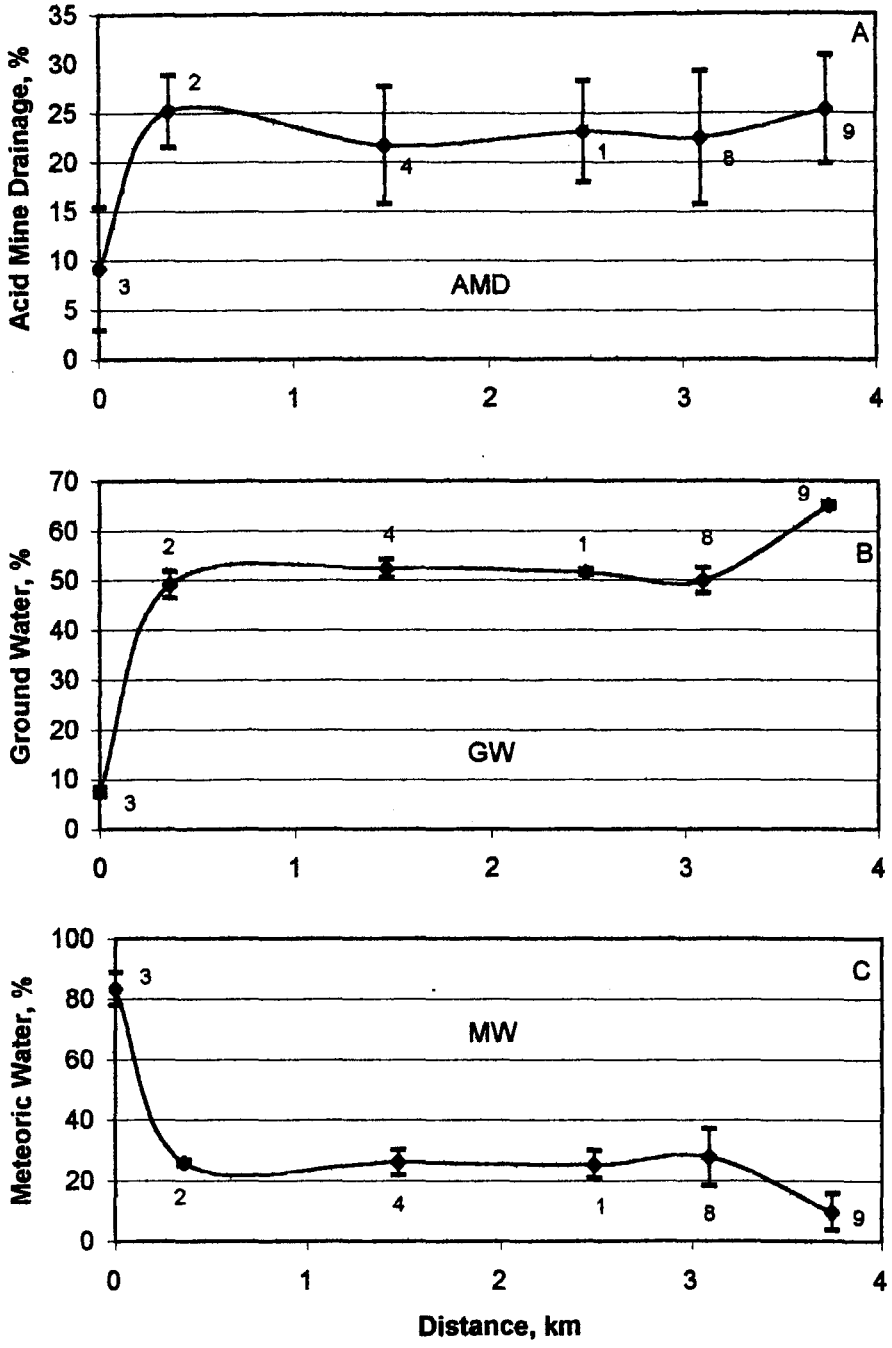


Figure 10. A. Average values of Acid Mine Drainage (AMD). From sample 3 to sample 2, the concentration of AMD sharply increases from 9% to 25%. B. The average value of groundwater increases downstream as more GW enters the creek. C. The stream begins with a high concentration of meteoric water which decreases as a result of increasing ground water and AMD. The error bars represent half of the value between between the average and the Na components.

Oxyanions

The elements that form oxyanions also have high concentrations in the ferric hydroxide precipitate: As = 67,700 ppm; V = 28,000 ppm; Cr = 5750 ppm; Se = 143 ppm; W = 122 ppm; Te = 38.1 ppm; Sb = 9.52 ppm; and Ta = 7.62 ppm. These elements are sorbed at low pH and may be released back into the water at neutral pH. This phenomenon is a matter of concern because some of these elements are toxic.

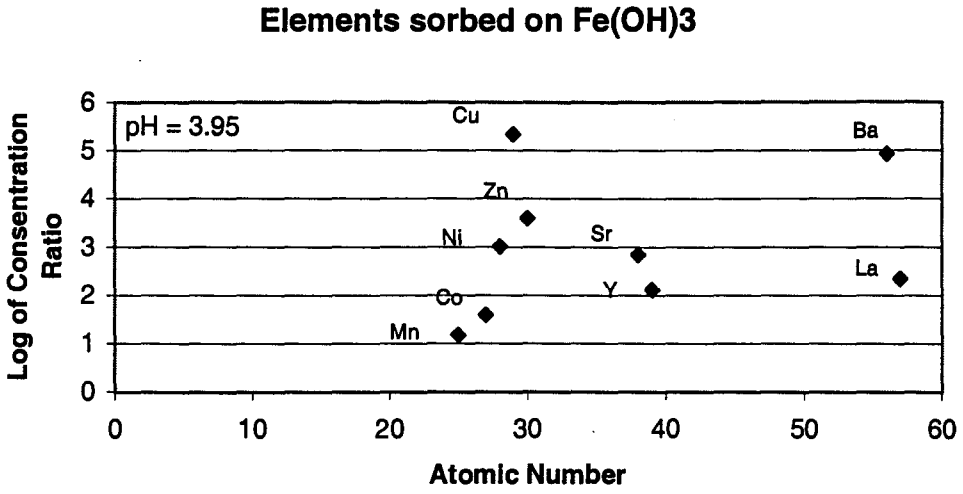
Concentration Ratios of Elements in the Ferric Hydroxide

In order to illustrate the extent of sorption that is occurring, the concentration ratios were calculated be dividing the concentrations of the elements in the ferric hydroxide by the concentrations of the elements in the water. The log of the concentration ratios are plotted against increasing atomic number in Figure 11. ICP-MS was used to analyze the ferric hydroxide, whereas ICP-OES was used to analyze the water, therefore only the concentration ratios of Cu, Ba, Zn, Ni, Sr, La, Y, Co and Mn were calculated.

Anions are preferentially sorbed to ferric hydroxide at low pH, but cations are also strongly sorbed at these particular conditions because the sulfate anion acts as a bridge to allow cations to sorb as well. At acidic conditions, the positive hydrogen ions attract SO_4^{2-} ions, which in turn attract the cations such as copper and barium.

Conclusion

The interpretations of the data obtained from Lexington and Rush Creeks give conclusive evidence that this drainage basin is contaminated even after 28 years of mining inactivity.



Concentration Raios	
Sediment (ug/g)/ Water (ug/mL)	
Cu	211,000
Ba	84,500
Zn	3890
Ni	1030
Sr	697
La	216
Y	131
Co	38.1
Mn	15.1

Figure 11. The log of the concentration ratios plotted against increasing atomic number. The cations are strongly sorbed at low pH due to the sorption of the sulfate ion.

The water is acidic and enriched in sediment and trace metals, producing water that is 25% acid-mine drainage. In addition to the problem of acid-mine drainage, there are also abundant metal ions sorbing to the sediment on the stream beds. These toxic metal ions can be released back into the water as pH conditions rise, and they can enter the food chain if humans and animals drink this water. It is evident that New Lexington is one of many mining towns in Ohio and elsewhere still facing problems related to coal mining in their past.

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Appendix

to Geochemistry of an Acid-contaminated Stream in New Lexington, Ohio
Linda M. Centeno

A. Threshold levels for trace elements in water

B. Analytical results of water samples

C. Sediment weight and concentration retained from filtering

D. Components of water in Lexington Creek

E. Concentrations of trace elements in ferric hydroxide, site 7

Appendix A

Threshold levels for trace elements in water (from Gough and Severson, 1995)

Element	Drinking Water mg/L	Aquatic Organisms mg/L	Sample 7 mg/L	Sample 10 mg/L
Arsenic	0.05	0.01	nd	0.073
Copper	1.0	0.005	0.011	0.068
Lead	0.05	0.01	nd	0.206
Manganese	0.2	0.02	44.81	14.34
Nickel	ng	0.025	0.776	0.227
Zinc	5.0	0.03	1.61	0.369

ng: no guidelines
nd: not detected

Appendix B

Analytical results of water samples. Analyzed by inductively coupled spectrometry (ICP-OES). The detection limit is given. Samples that do not reach the detection limit are left blank.

	Be (ppm)	Na (ppm)	Mg (ppm)	Al (ppm)	P (ppm)	K (ppm)	Ca (ppm)
detection limit	0.005	0.500	0.500	0.050	0.050	0.100	0.500
OSU-L-1	0.005	22.50	37.30	9.77	0.077	3.75	61.80
OSU-L-2	0.009	20.80	41.90	18.99	0.054	3.32	61.20
OSU-L-3		3.70	6.00	0.072		1.33	26.90
OSU-L-4	0.006	28.70	40.80	13.36	0.053	3.78	69.40
OSU-L-5	0.010	9.10	44.20	18.82	0.063	4.32	49.00
OSU-L-6		41.20	9.70	0.148		5.05	31.20
OSU-L-7	0.014	5.50	174.0	40.85	0.251	4.21	162.0
OSU-L-8		22.30	32.70	8.26		3.58	60.90
OSU-L-9		23.30	33.40	8.17	0.050	3.38	63.70
OSU-L-10		20.90	82.80	10.75	0.177	5.18	151.0
OSU-L-11		22.30	27.70	0.079		2.47	56.10
OSU-L-12		20.60	58.40	7.85	0.081	4.02	108.0

	Sc (ppm)	Ti (ppm)	V (ppm)	Cr (ppm)	Mn (ppm)	Fe (ppm)	Co (ppm)
detection limit	0.001	0.010	0.010	0.010	0.005	0.050	0.010
OSU-L-1					5.380	0.431	0.091
OSU-L-2					5.610	1.130	0.111
OSU-L-3					0.053	0.122	
OSU-L-4					5.750	0.793	0.103
OSU-L-5					9.980	14.38	0.218
OSU-L-6					0.208	0.427	0.012
OSU-L-7		0.019			44.81	35.03	0.749
OSU-L-8					4.720	1.240	0.088
OSU-L-9					4.840	2.120	0.087
OSU-L-10	0.004			0.014	14.34	0.761	0.168
OSU-L-11					0.382	0.119	
OSU-L-12					9.810	1.460	0.116

	Ni (ppm)	Cu (ppm)	Zn (ppm)	As (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)
detection limit	0.010	0.005	0.005	0.030	0.001	0.005	0.010
OSU-L-1	0.121	0.010	0.242		0.391	0.054	
OSU-L-2	0.191	0.005	0.425		0.383	0.093	
OSU-L-3	0.012	0.007	0.011		0.103		
OSU-L-4	0.155	0.025	0.304		0.546	0.074	
OSU-L-5	0.237	0.019	0.429		0.175	0.140	
OSU-L-6					0.113		
OSU-L-7	0.776	0.011	1.610		0.340	0.392	
OSU-L-8	0.107	0.015	0.221		0.354	0.048	
OSU-L-9	0.116	0.020	0.231		0.364	0.046	
OSU-L-10	0.227	0.068	0.369	0.073	0.647	0.056	0.037
OSU-L-11		0.010	0.005		0.208		
OSU-L-12	0.156	0.020	0.229		0.497	0.043	0.012

Appendix B continued

	Mo (ppm)	Ag (ppm)	Cd (ppm)	Sn (ppm)	Sb (ppm)	Ba (ppm)	La (ppm)
detection li	0.010	0.001	0.010	0.050	0.050	0.010	0.010
OSU-L-1		0.002				0.038	0.025
OSU-L-2						0.032	0.030
OSU-L-3						0.178	
OSU-L-4						0.048	0.022
OSU-L-5						0.030	0.048
OSU-L-6						0.145	
OSU-L-7		0.007				0.016	0.154
OSU-L-8		0.002				0.063	0.014
OSU-L-9						0.034	
OSU-L-10	0.010	0.009				0.026	0.050
OSU-L-11						0.045	
OSU-L-12		0.001				0.024	0.023

	W (ppm)	Pb (ppm)	Bi (ppm)
detection li	0.050	0.030	0.050
OSU-L-1			
OSU-L-2			
OSU-L-3			
OSU-L-4			
OSU-L-5			
OSU-L-6			
OSU-L-7			
OSU-L-8			
OSU-L-9			
OSU-L-10	0.073	0.206	
OSU-L-11			
OSU-L-12			

Appendix C

Sediment weight and concentration retained from filtering.

	sample#	Distance (km)	Volume (mL)	Dry sed (mg)	Concentration (ppm)	pH
	3	0	500	33.8	67.6	5.7
Lexington	2	0.36	500	56.1	112.2	3.7
Creek	4	1.47	500	78.6	157.2	3.2
	1	2.49	500	88.8	177.6	3.3
	8	3.09	500	75.1	150.2	4.0
	9	3.74	250	20.8	83.2	4.1
	7	0.94	500	402.1	804.2	3.95
Tributaries	5	1.22	250	2.3	9.2	2.6
and Rush	6	1.76	250	27.1	108.4	5.8
Creek	10	3.7	250	1598.3	6393.2	3.0
	11	4.08	250	7	28	6.2
	12	4.62	250	18	72	3.2

	AMD, %			GW, %			MW, %		
Sample #	Mg-Na	Ca-Na	Average	Mg-Na	Ca-Na	Average	Mg-Na	Ca-Na	Average
3	2.91	15.4	9.155	8.37	6.57	7.47	88.72	78.03	83.375
2	21.5	28.8	25.15	51.7	46.5	49.1	26.8	24.7	25.75
4	15.7	27.6	21.65	54.2	50.5	52.35	30.1	21.9	26.0
1	18.0	28.2	23.1	52.2	51.0	51.6	29.8	20.8	25.3
8	15.7	29.2	22.45	47.3	52.5	49.9	37.0	18.3	27.65
9	19.8	30.8	25.3	64.5	65.7	65.1	15.7	3.5	9.6

Appendix D. Acid Mine Drainage, Ground Water, and Meteoric Water components of Lexington Creek broken down into Magnesium-Sodium concentrations and Calcium-Sodium concentrations.

Appendix E

Concentrations of trace elements in solution and in ferric hydroxide, site 7 in ppm.

Element	Detection limit (ppm)	Concentrations in 100mL solution	Concentrations in ferric hydroxide
As	0.0001	0.711	67700
V	0.0001	0.294	28000
Zn	0.0001	0.0657	6260
Cr	0.0001	0.0604	5750
Cu	0.0001	0.0244	2320
Ba	0.0001	0.0142	1350
Zr	0.0001	0.0097	924
Ni	0.0001	0.0084	800
Mn	0.0001	0.0071	676
Pb	0.00001	0.00316	301
Sr	0.00001	0.00249	237
Se	0.0001	0.0015	143
W	0.00001	0.00128	122
Ce	0.00001	0.00107	102
Ga	0.00001	0.00084	80
Nd	0.00001	0.00075	71.4
Rb	0.0001	0.0006	57.1
Sn	0.00001	0.0006	57.1
Nb	0.00001	0.00058	55.2
Y	0.00001	0.00054	51.4
Sc	0.0001	0.0004	38.1
Te	0.0001	0.0004	38.1
La	0.00001	0.00035	33.3
Co	0.0001	0.0003	28.6
Sm	0.00001	0.00024	22.9
Gd	0.00001	0.00017	16.2
Pr	0.00001	0.00016	15.2
Cd	0.00001	0.00015	14.3
Dy	0.00001	0.00012	11.4
Th	0.00001	0.00012	11.4
Sb	0.0001	0.0001	9.52
Ta	0.00001	0.00008	7.62
U	0.00001	0.00008	7.62
Er	0.00001	0.00006	5.71
Cs	0.00001	0.00005	4.76
Eu	0.00001	0.00005	4.76
Yb	0.00001	0.00004	3.81
Hf	0.00001	0.00003	2.86
Ho	0.00001	0.00002	1.90
Tl	0.00001	0.00002	1.90
In	0.00001	0.00001	0.952
Be	0.0001	nd	nd
Mo	0.001	nd	nd
Tm	0.00001	nd	nd
Lu	0.00005	nd	nd
Hg	0.0002	nd	nd
Bi	0.00001	nd	nd